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THE CARBON DIOXIDE: HEAT RATIO IN CATTLE

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It was recently suggested to us by Dr. F. G. Benedict that if the ratio of the carbon dioxide excreted to the heat produced by cattle should prove to be sufficiently constant, this fact might be utilized as the basis for determinations of the energy metabolism of this species which would be approximately correct and which would require only a comparatively simple technique. In view of the great value which such a simplified method would have, especially for agricultural investigators, and of the further fact that a new form of respiration apparatus designed to be used in this manner has been constructed by Benedict in coöperation with the New Hampshire Agricultural Experiment Station, we have thought it worth while to study the results of our calorimetric experiments on cattle from this point of view and we present the results of that study herewith.[1]

These experiments were made with the Atwater-Rosa respiration calorimeter which has been in use here since 1901, the heat production as well as the elimination of carbon dioxide being measured, and are, so far as we are aware, the only direct determinations of the heat production of this species. The measured heat production has been compared with the carbon dioxide elimination in 188 24-hour periods.[2] The carbon dioxide included, of course, the considerable amount arising from the methane fermentation in the rumen. The following results were obtained for the heat expressed in kilogram calories divided by the carbon dioxide expressed in grams.

CARBON DIOXIDE : HEAT RATIO OF CATTLE

Range	2.1500 to 3.1500
Mean value	2.4947 ± 0.0085
Standard deviation	0.1713 ± 0.0060
Median	2.4938
Theoretical mode	2.4974
Error of single variate	±0.12
Coefficient of variability	6.87%

In 51 of these periods we have also data for the carbon dioxide and heat production of the animals in the standing and lying positions respectively. A comparison of these shows a somewhat smaller ratio in the lying than in the standing position.

CARBON DIOXIDE : HEAT RATIO OF CATTLE

	STANDING	LYING
Range	1.8600 to 2.9400	1.6900 to 2.5700
Mean value	2.5129 ± 0.0185	2.2529 ± 0.0149
Standard deviation	0.196 ± 0.013	0.158 ± 0.011
Median	2.5020	2.2713
Theoretical mode	2.4802	2.3081
Error of single variate	±0.13	±0.11
Coefficient of variability	7.80%	7.01%

A further study of the results indicated that the rather wide range in the single values of the CO_2 : heat ratio was caused in large degree by variations in the amount of feed consumed, the ratio tending to decrease as the amount of feed increased. This is what would have been expected for two reasons. First, the CO_2 : heat ratio for the methane fermentation, although not very satisfactorily determined, is undoubtedly much lower than that due to the tissue metabolism of the animal and as the feed is increased this constitutes an increasing proportion of the total elimination. Second, it is clear that the formation of fat from carbohydrates which takes place on a heavy ration would tend to lower the ratio; while, on the other hand, the oxidation of body fat on an insufficient ration would tend to increase the ratio. It should be noted also that our subjects were performing no external work and while not absolutely at rest were for the most part standing or lying quietly. Any considerable muscular exertion would doubtless have materially increased the ratio.

In 99 48-hour experiments, the factor of the varying size of the subjects being eliminated by computing all the results per kilogram of live weight, it appeared from a graph in which the abscissas represented the total weights of feed consumed and the ordinates, respectively, the grams of carbon dioxide excreted, the calories of heat measured and the ratio Heat/CO_2, that the individual results grouped themselves quite closely about three straight lines which could be represented by the three following linear equations, in which

x = Air-dry weight of feed in grams per kilogram of live weight

y_1 = Calories of measured heat per kilogram live weight

y_2 = Grams of CO_2 per kilogram live weight

$$y_3 = \frac{\text{Heat}}{CO_2} = \frac{y_1}{y_2}$$

(1) $y_1 = 0.869x + 14.176$

(2) $y_2 = 0.455x + 4.365$

(3) $y_3 = -0.0226x + 2.802.$

A computation of the closeness of fit of the lines represented by the foregoing equations to the individual results gives the following values for the index (Δ) and the probability (P).

$$\Delta_1 = 4.489 \qquad P_1 = 0.9508$$
$$\Delta_2 = 2.467 \qquad P_2 = 0.9640$$
$$\Delta_3 = 0.663 \qquad P_3 = 0.9986$$

It would perhaps have been preferable to make the comparisons with the dry matter of the feed consumed. No succulent feeds, however, were contained in the rations and it does not seem probable that the slight differences in moisture content can have materially affected the conclusions. We have not attempted to distinguish between the effects of different kinds or classes of feeding stuffs and doubt whether our data are sufficiently extensive to warrant it.

It would appear from the foregoing data that within the range of these experiments, i. e., with feed varying from 5 to 27 grams per kilogram live weight, equation (3) may be used for computing the CO_2 : heat ratio of cattle when their live weight and the amount of feed consumed are known, and that by the use of this ratio the heat production may be computed from the observed CO_2 production with a good degree of accuracy, at least for animals on dry feed and not performing work.

It should be noted, however, that the values of y_3 computed from equation (3) differ slightly from the ratios computed from the corresponding values of y_1 and y_2, indicating that y_3 is not a strictly linear function of x. The discrepancy does not appear sufficient to affect materially the computation of the heat production from the CO_2 on the amounts of feed used in these experiments but for the fasting animal, i. e., when $x = 0$, the discrepancy is much more considerable, viz.:

$$\frac{y_1}{y_2} = 3.25 \qquad y_3 = 2.80$$

It appears probable that the values of y_3 would be represented more exactly by a line slightly convex toward the horizontal axis and curving somewhat more sharply upward as the value of x approaches zero, and that for very small amounts of feed the CO_2 : heat ratio computed from the values of y_1 and y_2 is more accurate than that computed from equation (3). This conclusion is strengthened by the fact that the fasting value thus obtained approximates quite closely that observed by Benedict in his experiments on fasting men.

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[1] The entire credit for the mathematical discussion of the results as well as for the laborious computations involved is due to Mr. Braman.

[2] In most instances two of these periods constituted the two halves of one of the 48-hour experiments mentioned subsequently.